

1                   SYSTEM AND APPARATUS FOR ACCELERATING  
2                   MASS TRANSFER OF A GAS INTO A LIQUID  
3                   Specification

4                   Field of the Invention

5                   Accelerating the solution and equilibrium of gases injected  
6                   into a liquid, such as air, oxygen, ozone or chlorine in the  
7                   treatment of liquids, for example water.

8                   Background of the Invention

9                   Infusion of gases into a flowing stream of liquid is common-  
10                  place in many industries. Perhaps the best-known example is  
11                  treatment of water with ozone, oxygen, air, or other gases for  
12                  purification purposes. There are many techniques to accomplish  
13                  this, all of which involve presenting the gas to the liquid at a  
14                  liquid/gas interface so the gas (or some of it) will dissolve in  
15                  the liquid, passing across the interface.

16                  There are several most frequently encountered techniques for  
17                  creating the interface. One example is to spray the water into  
18                  air so the surfaces of the liquid droplets form the interface.  
19                  Another is to pour the liquid over extended surfaces such as  
20                  Raschig rings to spread out the surface of the water to form an  
21                  extended interface. Another is the injection of bubbles into a  
22                  body of water. This technique can be accomplished simply by  
23                  bubbling gas through the water, or as more pertinent to this  
24                  invention by injecting the gas into a pressurized closed flowing

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1 stream of water with the use of an aspirating injector.

2 In the latter two techniques- bubbling and injecting, the  
3 interface is the concave boundary of the gas bubbles, rather than  
4 the flat or convex exposed surface of the water. The transfer of  
5 the gas into the liquid requires its passage across the interface  
6 formed by the gas trapped in the bubbles. Although there are  
7 other pertinent parameters, those of most importance are the  
8 surface area of the bubbles and the system pressure.

9 It is well-known that a large number of smaller bubbles will  
10 have a larger total interface area than a single large bubble  
11 containing the same total volume of gas. It follows that the  
12 rate of transfer of a given volume of gas will be accelerated by  
13 reduction of the size of the bubbles, considering equal volumes  
14 of gas.

15 Also, the solubility of a gas in a liquid is a direct  
16 function of the pressure (Henry's Law). More gas will be  
17 dissolved in a given liquid at a higher pressure (at the same  
18 temperature) than the same gas at a lower pressure.

19 Another parameter, which is more related to dynamics than to  
20 pressure and area at the interface is the partial pressure and  
21 the concentration of the gas intended to be transferred at the  
22 interface. For example, when air is injected the gas desired to  
23 be transferred is oxygen, rather than nitrogen and the other  
24 constituents of air. Their rates of transfer may not be equal,

1 and it is possible that the concentration of oxygen at the  
2 interface may be lower than the concentration farther away from  
3 it. While the effect may be small for each bubble, in this  
4 invention many thousands of small bubbles are contemplated and  
5 even minor differences can provide major effects.

6 Because in some applications there may even be an exchange  
7 of gases from the water into the bubbles and vice versa, any  
8 means to accelerate the transfer is a welcome improvement. In  
9 conventional installations, it is common practice simply to  
10 employ enough volume of apparatus to provide time for the  
11 interchange to occur. This frequently necessitates the use of  
12 large tanks and towers, or large conduitry. These are expensive  
13 in themselves and require substantial "real estate" to  
14 accommodate them in major systems.

15 Instead of the above, or in addition to it, apparatus is  
16 known to stir or otherwise mix the gas and liquid. For example,  
17 static mixers are known which function to cause internal movement  
18 in the fluid stream with the objective of providing a uniform  
19 "availability" of the gas bubbles and liquids, thereby to assure  
20 a uniformity of fluid in the system, avoiding voids and pockets,  
21 and local concentrations.

22 Such static mixers ordinarily redirect the stream or  
23 portions of it to change a smooth stream into a path with cross-  
24 currents, orbital currents, and the like. In some, downstream-

1 directed stream converge into one another as they flow through  
2 the mixer. Their objective is to mix the components of the  
3 stream to approach uniformity and eliminate regions of greater or  
4 lesser concentration. They are as useful in blending syrups as  
5 in mixing liquids and gases.

6 However, that is not the objective of this invention.  
7 Instead, this invention is directed toward the vigorous and rapid  
8 continuing renewal of the interface conditions between the bubble  
9 and the surrounding liquid. The objectives are very different  
10 from those of the static mixer.

11 It is further useful to emphasize that the stream in this  
12 system, while closed and under pressure is not incompressible.  
13 In fact it is compressible, and in a sense elastic. This is  
14 because of its substantial gas content which often may be as  
15 high, volumetrically, as 20%. The liquid is, of course not  
16 compressible, but because of the gas, the combined stream is.  
17 Therefore changes in pressure, physical forces such as abrupt  
18 accelerations, impacts and reversals, result in important changes  
19 in the shape and size of the bubbles. The consequence is that  
20 the composition at the interface of the gas bubble with the  
21 liquid is being constantly renewed.

22 While neither the reactor nor the collider has any moving  
23 parts, it is not a static mixer in the conventional sense. The  
24 exercise of this stream is far from orderly. Its abrupt

1 reversals, eddy regions and internal nozzles and joggles, all  
2 combine to cause this compressible stream to undergo physical  
3 reactions that profoundly accelerate the solution of the gas into  
4 the liquid.

5 The applicant has discovered that the rapid renewal of the  
6 interfaces and of the gas concentration directly contiguous to  
7 this interface has an extraordinary cumulative effect on the  
8 transfer of gases. He has also discovered that a most  
9 appropriate way to accomplish this is by the "exercising" of the  
10 gas bubbles, for example by abrupt changes in direction of the  
11 stream, of passing the stream through sequential orifices, and of  
12 colliding streams of bubble-containing liquid. These techniques  
13 can be used singly or in any combination. Such exercise of the  
14 bubbles results in a surprisingly effective and very rapid  
15 solution and equilibrium of the gas.

16 This invention overcomes the disadvantages of the prior art  
17 by including in a flowing system under pressure, a collider or a  
18 reactor of surprisingly small bulk, or both, located downstream  
19 from an aspirator injector. For some applications this may  
20 advantageously be followed by an optional gas separator to remove  
21 undissolved excess gas.

22 This invention provides an optimum system which provides  
23 surprisingly beneficial results. However, there are many  
24 applications where ultimate performance is unnecessary. In this,

1 an installation of lesser complexity and bulk can provide a  
2 myriad of small bubbles of gas to be dissolved and treated with  
3 sufficiently acceptable results.

4 The reader is entitled to ask why there is an advantage in  
5 accelerating a process which, if given enough time would occur  
6 anyway. The answer is that for a given volume of liquid and  
7 desired attained result it is possible to reduce the bulk and  
8 footprint of the system (and thereby its cost), and to reduce the  
9 dwell time of the liquid during treatment.

10 There is the additional advantage that the system need not  
11 be "over-dosed" in order to be certain that sufficient gas is  
12 available, and then requiring the stripping off a large excess  
13 quantity of treatment gas.

14 The rapid renewal and abrupt changes of the interfaces  
15 caused by the fluid manipulations of this invention result in a  
16 surprising reduction in dwell time and bulk of the process  
17 equipment. When the preferred embodiment of the system is  
18 utilized, the dwell time can often be reduced by as much as 60%,  
19 with an attendant reduction of required real estate and  
20 investment, compared to known systems.

21 Brief Description of the Invention

22 The presently preferred embodiment of the invention receives  
23 liquid under pressure to be treated by an injected gas. The  
24 liquid flows into an aspirator injector which injects the gas

1 into the liquid. From the injector, the flow is to a collider  
2 and a reactor, in either order, in which the stream is subjected  
3 to vigorous exercising including abrupt changes in motion rapidly  
4 to renew the gas/liquid interfaces.

5 From these (or from either one if only one is used) the  
6 stream is discharge, preferably through a centrifugal gas/liquid  
7 separator.

8 According to a preferred but optional feature of the  
9 invention, the collider provides for two colliding stream which  
10 create the vigorous action.

11 According to yet another preferred but optional feature of  
12 the invention, the reactor includes a cylinder having an upstream  
13 chamber and a downstream chamber with a partial barrier between  
14 them. An inlet nozzle directs a strong stream against a  
15 reflector surface on the barrier, which reverses the direction of  
16 flow in the chamber to a cove surface that again abruptly  
17 reflects the stream. The stream flows through joggle slots into  
18 the downstream chamber where it preferably strikes a cove surface  
19 that reflects the stream to a downstream facing reflecting  
20 surface, from which the stream resumes its flow toward the  
21 separator.

22 The above and other features of this invention will be fully  
23 understood from the following detailed description and the  
24 accompanying drawings, in which:

1      Brief Description of the Drawings

2      Fig. 1 is a schematic drawing showing the preferred circuit  
3      of this invention;

4      Fig. 2 is an axial cross-section of the preferred embodiment  
5      of injector;

6      Fig. 3 is an end view taken at line 3-3 in Fig. 2;

7      Fig. 4 is an end view taken at line 4-4 in Fig. 2;

8      Fig. 5 is a side view, partly in cutaway cross-section and  
9      partly in phantom line of the preferred collider;

10     Fig. 6 is a cross-section taken at line 6-6 in Fig. 5;

11     Fig. 7 is a cross-section of the preferred nozzle for use in  
12 Fig. 5, a simplified nozzle being shown in Fig. 5;

13     Fig. 8 is an end view taken at line 8-8 in Fig. 7;

14     Fig. 9 is a side view of the presently preferred reactor;

15     Fig. 10 is a cross-section taken at line 10-10 in Fig. 9;

16     Fig. 11 is an oblique view of a portion of the reactor of  
17 Fig. 9 removed for purposes of illustration;

18     Fig. 12 is a cross-section taken at line 12-12 in Fig. 10;

19     Fig. 13 is a cross section taken at line 13-13 in Fig. 10;  
20 and

21     Fig. 14 is an axial cross-section of a centrifugal separator  
22 useful in the system of Fig. 1.

23      Detailed Description of the Invention

24      The presently preferred system 20 according to the invention

1 is shown in Fig. 1. This is the optimum system, which offers all  
2 of the advantages of the invention. As will later be apparent,  
3 parts of it may be modified or eliminated, in order to adjust the  
4 performance of one of the components or to accept a lesser  
5 performance of the system. In the latter event, the lesser  
6 performance may be sufficient for the intended application, and  
7 the reduced cost of the eliminated component is attractive.

8 Systems according to this invention are capital expenses,  
9 often paid with tax dollars. Reduction in costs for equivalent  
10 performance often lead to granted contracts. It is a substantial  
11 advantage that this system can use all or less than all of its  
12 components, and in every situation will provide equivalent or  
13 better performance for less equipment cost, and with less real  
14 estate to accommodate it, than presently-known systems used for  
15 the same purposes.

16 The system is adapted to accept and to treat a liquid such  
17 as water from a source 21. Source 21 may be such as a reservoir,  
18 a tank, a sump, a lake, or some other storage means for the  
19 liquid intended to be treated. The most common use for this  
20 system will be the treatment of water with a treatment gas, for  
21 example to sanitize it for domestic purposes, or to reduce a  
22 contaminant so the stream can be discharged into the environment,  
23 perhaps into a sewer or a river.

24 The water must be treated under pressure. Accordingly, a

1 pump 22 receives liquid from the source through conduit 23 and  
2 impels it through conduit 24 to an aspirating injector 25.

3 It is the function of injector 25 to aspirate into the  
4 stream a treatment gas from a gas source 26 into the stream in a  
5 myriad of small gas bubbles. A regulator valve 27 is optionally  
6 placed between the injector and the gas source 26.

7 Conduit 24 receives the bubble-laden stream from the  
8 injector, and conveys it to a collider 32 through two branches  
9 33, 34. As will later be shown, these inject the stream into the  
10 collider, from which, recombined, it exits the collider through a  
11 conduit 35.

12 In turn, conduit 35 conveys the stream to a reactor 40. A  
13 conduit 41 conveys the stream from the reactor to a separator 42,  
14 which functions to strip undissolved or entrained gas from the  
15 liquid. A gas vent 43 relieves gases from the separator, and  
16 discharges it to a point of disposal through conduit 44. Under  
17 some circumstances a vacuum pump 45 may be connected to conduit  
18 44.

19 Water stripped of residual gases exits the separator through  
20 conduit 47. System pressure may be further regulated and  
21 maintained by a pump 48 under control of a pressure regulator  
22 loop 49.

23 The term "fluid release" is sometimes used herein to denote  
24 structure which will enable the liquid to leave the system while

1 still maintaining system pressure. This may include the  
2 separator and its downstream valving, or if the separator is not  
3 used, then only valving.

4 The foregoing is a description of the most complete system.  
5 The individual components will now be described, and some will be  
6 claimed individually as such.

7 The presently-preferred form of injector 25 to be used in  
8 this system is shown in Figs. 2-4. It is a member of the class  
9 of aspirating injectors shown in United States patents Nos.  
10 4,123,800 and 5,863,128, issued to Angelo L. Mazzei. The latter  
11 one is illustrated in Figs. 2-4, although the simpler embodiment  
12 shown in the former patent is also useful in the invention. Both  
13 of these patents are incorporated herein and made a part hereof  
14 by reference in their entirety for their showing of the details  
15 of construction of useful injectors. In particular the reader is  
16 referred to patent No. 5,863,128 for a complete discussion of its  
17 features. Figs 2-4 show injector 25. Such injectors can be  
18 purchased from Mazzei Injector Corporation at 11101 Mountain View  
19 Road, Bakersfield, California 93307.

20 Known systems utilizing such an injector and a separator are  
21 shown in United States patents Nos. 5,674,312 issued to Angelo L.  
22 Mazzei and 6,193,893 issued to Angelo L. Mazzei and Raymond M.  
23 Meyer. Both of these patents are incorporated herein and made a  
24 part hereof by reference for their showing of systems that

1 utilize both an injector and a separator, and their teaching of  
2 the management of such systems.

3 A body 60 has an axial central passage 61 extending from  
4 inlet end 62 to outlet end 63. Conduit 24 is connected to inlet  
5 end 62. Conduit 30 is connected to outlet end 63.

6 The passage is circular. An inlet section 64 is followed in  
7 the downstream direction by a converging section 65, a  
8 substantially cylindrical throat section 66, and an expanding  
9 section 67 in that order.

10 Supply port 68 is connected to conduit 69, and enters into a  
11 circular groove 70 through which treatment gases are injected  
12 into the throat section. Groove 70 (or injection ports instead)  
13 are preferably located close to the end of the converging  
14 section.

15 Twisting vanes 71 are formed in the converging section.  
16 Straightening vanes 72 are formed in the diverging section.  
17 These project into the stream to the limited extent described in  
18 patent No. 5,863,128. Twisting vanes 71 give a small circular  
19 "twist" to the outer boundary of the stream. Straightening vanes  
20 72 remove some of this twist. These vanes are optional. With  
21 the loss of only some advantage, injectors without them will also  
22 function well. Patent No. 4,123,800 illustrates such an  
23 injector.

24 The effluent stream from the injector is liquid which

1 includes within it a myriad of small bubbles of the treatment gas  
2 received from source 26 (atmosphere, tank, compressor). The  
3 stream, having been reasonably well mixed, is dispatched by  
4 system pressure to collider 32. The collider is the first of two  
5 devices which "exercise" the stream flow, and thereby also the  
6 bubbles, their contents, and their interfaces.

7       The preferred embodiment of collider 32 is shown in Figs. 5-  
8 8. The collider comprises a body 81 forming a closed internal  
9 chamber 82, with a pair of end walls 83, 84. The wall 85 between  
10 them is preferably cylindrical. Exit port 86 departs from the  
11 chamber at a right angle to the central axis 87 of the cylinder  
12 wall.

13       Nozzles 88, 89 are respectively connected to branches 33 and  
14 34. They are placed on axis 87, and are directed into the  
15 chamber. In the arrangement shown, which usually will be  
16 preferred, they are axially pointed directly at each other.

17       Instead of being axially aligned and directly opposed,  
18 these nozzles may be pointed with their streams intersecting and  
19 forming between them an angle greater than zero degrees, and not  
20 greater than about 90 degrees. Then the streams will not axially  
21 collide, but instead will collide obliquely, so as to provide  
22 impulse to movement of the fluid in a non-symmetrical manner.

23       Nozzles 88 and 89 may if desired be simple converging types  
24 with converging surfaces just before their exit ports. Such

1 simple nozzles may be used with considerable effect in this  
2 system. However, it has been found that utilizing the nozzles  
3 shown in United States patent No. 5,863,128 issued to Angelo L.  
4 Mazzei, provides an improvement to the function of the basic  
5 collider. As best shown in Figs. 6-8, the preferred nozzle  
6 comprises a body 90. This body is essentially the same as the  
7 inlet and converging sections of the injector. It includes an  
8 inlet section 92 connected to conduit 33 or 34. The body is  
9 mounted to a respective end wall of the collider. The nozzle has  
10 a central orifice 93 at its outlet end 94, directing its stream  
11 into the chamber.

12 In the preferred embodiment, the converging section has, on  
13 its surface 95 a plurality of twisting vanes 96, which provide  
14 rotation to a limited outer portion of the flowing stream. Full  
15 discussion of this feature will be found in United States patent  
16 No. 5,894,995, issued to Angelo L. Mazzei, which patent is  
17 incorporated herein and made a part hereof by reference for its  
18 showing of the construction and theory of a nozzle of this type.  
19 The vanes are not necessary to this system, but they do assist in  
20 creating movements of fluid in the chamber.

21 Attention is called to regions 98, 99 in the chamber, to the  
22 side of the nozzles. These are regions in which liquid eddies,  
23 rather as in a pocket, subsidiary to the major flow resulting  
24 from the collision of the streams, and their exit out the exit

1 port. These eddy current regions provide, for some of the  
2 liquid, an increased dwell time that enables still more rapid  
3 solution of the gases.

4 The dimensions of the collider are arbitrary. The important  
5 relationship is for the directed flow patterns of the nozzles to  
6 intersect one another, preferably directly on, but in some  
7 applications, at an included angle between them of not more than  
8 about 90 degrees. The intended and effective result is attained  
9 as the consequence of the collisions of the streams, which cause  
10 rapid changes of direction and shape of the bubbles, and  
11 secondarily, time spent in eddies in some regions of the  
12 collider. The benefits of the nozzle, which has important  
13 advantages when used to inject a liquid into a body of the  
14 liquid, are described in the said patent No. 5,894,995 to Mazzei.  
15 It should be remembered that this system is filled with fluid  
16 (both gas and liquid), all of which is under pressure.

17 Reactor 40 is a more complicated structure. In a relatively  
18 short structural length it provides a mean path that is not only  
19 significantly longer than its structure, but provides a quite  
20 complex path with many excursions from a straight-through path,  
21 leading to collisions with structure and with other currents in a  
22 complicated stream. The structure itself is rather straight-  
23 forward, and readily molded to shape.

24 Reactor 40 comprises a body 100 having a cylindrical inner

1 wall 101 forming a cylinder 102 with a central axis 103. An  
2 axial inlet port 104 receives the stream from conduit 35. An  
3 axial outlet port 105 discharges the stream to conduit 41.

4 A nozzle 106 in the inlet port is preferably a converging  
5 type nozzle that forms a concentrated, nearly cylindrical stream  
6 directed axially into the chamber.

7 A partial barrier 110 extends laterally across the chamber.  
8 It is "partial" because some flow patterns are permitted past it.  
9 In its central area, it acts as a barrier that is also a  
10 reflector of at least part of the stream. Because of its  
11 complexity the barrier is most conveniently formed in a mold, at  
12 least for sizes up to about 3 inches in diameter.

13 It divides the internal cylinder into a first chamber 111  
14 and a second chamber 112. Chamber 111 is upstream and in  
15 communication with the nozzle. Chamber 112 is downstream and  
16 communication with the outlet port. Gross flow is from the inlet  
17 port to the outlet port, and it all must pass the barrier. The  
18 barrier includes an upstream-facing reflecting surface 113, which  
19 is directly aligned with the nozzle so as to receive and reflect  
20 at least the major portion of its stream. It should be  
21 remembered that this reactor is filled with fluid in many modes  
22 of motion, so that, while much of the nozzle discharge directly  
23 impacts surface 113, a significant part of it will become  
24 involved with other flow patterns.

1       The reflecting surface is preferably concave, so that, when  
2       the nozzle discharge strikes it as a stream, the reflected stream  
3       flares outwardly as it returns in a generally upstream direction.  
4       This returning flow in turn strikes a circular cove 114 adjacent  
5       to the nozzle, from which it is returned in a downstream  
6       direction. Thus, this far the stream has undergone two reversals  
7       of direction, both abrupt. In addition, there are intersections  
8       of various parts of the general stream- for example the  
9       intersection of part of the nozzle stream with the reflected  
10      stream, the interaction of the reflected stream with the cove,  
11      and its reflected stream with the first reflected stream.

12      The barrier further includes a plurality of axially  
13      extending arcuate blades 115, 116, 117, 118. These blades are  
14      angularly spaced from one another so as to provide slots 119,  
15      120, 121 and 122 between them. The reflecting surface includes  
16      an annular surface 123 between the blades and the impingement  
17      surface. This provides yet another surface on which downstream-  
18      directed fluid can strike. It is continuous at the blades, but  
19      is pierced by the slots. It provides not only for impact, but  
20      also for compression of the stream, especially as the stream that  
21      strikes between the slot moves laterally to join fluid that flows  
22      directly into the slot and through a relieved portion 125. While  
23      some of the stream might flow directly from the nozzle to these  
24      relieved portions (the shortest possible path), the great

1 preponderance of the flow will experience at least three impacts,  
2 plus an indeterminate number of mixings with intersecting  
3 currents or eddies. Especially at the upstream end of the first  
4 chamber around its edge there is a region likely to produce eddy  
5 currents for still more mixing.

6 The gross stream passes into the second (downstream) chamber  
7 112. In its preferred embodiment, the downstream chamber  
8 subjects the flow to further mixing and abrupt reversal. In some  
9 embodiments, this will not be necessary because flow patterns in  
10 the first (upstream) chamber will have been sufficient. In that  
11 event, the downstream chamber may be formed as a simple funnel  
12 (not shown), discharging to conduit 41.

13 Joggle surfaces 124, 125, 126 and 127 are formed by upstream  
14 ends of blades 128, 129, 130 and 131 slots. 132, 133, 134 and  
15 135 are formed between these blades in the downstream chamber.  
16 They extend to a cove surface 136. As can be seen, a portion of  
17 the flow through the slots can be straight-through, but part of  
18 it encounters the joggles. These joggles direct a portion of the  
19 stream into the direct stream through the direct path between the  
20 slots creating still another mixing of the liquid and the  
21 bubbles.

22 The joggles preferably "blank" about one half of the width  
23 of the slots, so that portion of the stream is diverted into the  
24 remainder which passes straight through. This not only causes

1 another violent mixing, but also forms restrictions in the nature  
2 of nozzles which accelerate the flow and locally reduce the  
3 pressure. This is a further "exercising" of the bubbles. The  
4 total areas of the open aperture at the joggles should about  
5 equal the cross-section area of the nozzle inlet, although this  
6 is not a limiting value.

7 On the downstream side of the barrier there is a reflecting  
8 surface which reflects the stream from the cove to the outlet  
9 port. Surface 137 may be concave or flat as desired. The  
10 reflective and edging flow resemble those in the upstream  
11 chamber.

12 Reactor 40 thereby provides in a comparatively small and  
13 short device the equivalent of long conduits or large tanks. In  
14 fact, a 3 inch long reactor with about 1 1/2 inch internal  
15 diameter has been found to be the equivalent of a 400 gallon  
16 tank, which usually must be built from stainless steel. The  
17 savings in equipment cost and of real estate are real and are  
18 dramatic.

19 When the stream leaves reactor 40, it will have received the  
20 intended benefits of this invention. At this point, the stream  
21 may be discharged from the system, with both the liquid (with  
22 dissolved gas) and entrained gas (as bubbles). The pressure in  
23 the system must be maintained, so the exit will be through a  
24 controlled release such as a pressure regulator that permits

1 escape of fluid, but without reducing the system pressure.

2       However, the effluent would be rather effervescent, and also  
3 perhaps the entrained gases would object to. For example, if  
4 ozone or chlorine were used in excess for treatment, the bubbles  
5 would need to be removed, and the gases recirculated or otherwise  
6 disposed of.

7       An optimum gas separator is shown in Fig. 11. It requires  
8 no separate power supply, and operates solely on system pressure.  
9 It is a centrifugal separator of the type shown in United States  
10 patent No. 5,622,545 issued to Angelo L. Mazzei and Steven D.  
11 Ford. This patent is incorporated herein in its entirety by  
12 reference for its showing. Full details of construction, theory  
13 and operation of such a separator can be obtained from a reading  
14 of this patent.

15       Separator 42 includes a cylindrical vortex tube 150 that  
16 forms a centrifuge chamber 151. Its upper wall is pierced by  
17 injector ports 152 that convey the stream under pressure from  
18 nozzles 153 through a cuff-like supply chamber 154 to provide a  
19 rapidly swirling flow around and down the vortex tube. The  
20 heavier liquid will segregate to the wall, and the gas will  
21 segregate near the axis.

22       A separator tube 160 extends down the center of the vortex  
23 tube. It has slots 161 that permit the gases to flow into the  
24 tube and up through exit port 162. Liquid flows out the bottom

1 through exit port 163.

2       Above the exit port is a gas relief valve 165. This valve  
3 is responsive to the interface between liquid and gas, and will  
4 open to release gas if the liquid level in the separator chamber  
5 is too low.

6       The system described to this point incorporates all of the  
7 potential advantages of the invention. However, all features  
8 will not always be needed. For example, if it is agreeable to  
9 flash the residual gases into the atmosphere no separator will be  
10 needed. Also, other types of separators may instead be used,  
11 including settling tanks, for example.

12      In many systems, either of the collider or reactor may be  
13 used without the other, and when both are used, their order in  
14 the system can be reversed. Whatever the arrangement, it will  
15 include an aspirating injector for the system.

16      The collider and reactor are unique in their own right, and  
17 do not require an injector to provide advantages of accelerating  
18 solution of gases, although the combination is beneficial.  
19 Persons skilled in the art will recognize other uses for these  
20 unique devices.

21      This invention thereby provides a unique system to  
22 accelerate the solution of gases, and unique individual pieces of  
23 apparatus (the collider and reactor) with benefits of their own.

24      This invention is not to be limited by the embodiment shown

1       in the drawings and described in the description, which is given  
2       by way of example and not of limitation, but only in accordance  
3       with the scope of the appended claims.